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VIBRATION TEST ON RCC SLAB BRIDGE MODEL FOR CONDITION MONITORING

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ABSTRACT

Continuous condition monitoring of bridge structures in India becomes essential because many of the bridges were constructed long ago with loading conditions as per old codal provisions. The bridges have become weak and distressed due to the increasing vehicular traffic which in turn reduces the performance and safety of the bridge. Also the information about the old bridges such as capacity information is not available. The problem is more pronounced in rural areas compared to urban places where visual inspection is frequent and necessary infrastructure is available for immediate revival. Vibration based condition monitoring detects structural integrity and conveys a warning message if the integrity is defective. This paper presents the condition monitoring of RCC slab bridge deck which is designed for rural areas, by conducting test on small scale model. The test specimen is a ¼th scale deck slab of 1500 mm long, 1100 mm wide and 110 mm thick. The experimental and analytical results are presented in terms of frequency, deflection, crack width and stiffness.

Key words: Accelerometer, Condition Monitoring, Damage detection, Natural frequency, Vibration

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1. INTRODUCTION

Bridges form an essential and vital mode of road transport that plays a major role in shaping the economical, political, cultural and social aspects of a nation. Reinforced Concrete bridge decks deteriorate faster than other bridge elements due to direct exposure to environment and also by increasing traffic loads. Previously, there were many bridges collapses that have seriously disrupted the vehicular traffic while causing extensive damages to the lives of users. There are many factors which lead to degradation of slab bridges. Primary factor is due to inadequate inspection and monitoring infrastructure and the consequences to this problem is critical that needs repair, the result leads to repair cost that becomes comparable to replacement costs. Other factor is due to increasing the loads or design requirements over the time which results the structure unsafe and replacements are required.

Nobuhiro et al[1] proposed a prototype of accelerometer and piezoelectric cable sensor for vibration monitoring system, that allows easy evaluation of a bridge structure. They concluded that the accelerometers were used for vibration measurements and also it could be used to detect impactloads acting on bridges. Umesh[2] discussed recent research activities in structural health monitoring system using Fibre Bragg Grating sensor and also discussed strain sensing in a concrete bridge. Bouguerra et al[5] conducted an experimental study on the behavior of FRP reinforced concrete bridge deck slabs under concentrated loads and concluded that transverse reinforcement is the main factor affects the crack width. Punching of the slabs are significantly affected by compressive strength of the concrete and the slab thickness. Nagata et al[9] discussed the vibration properties at each damage state and identified the relation between damaged stages and reduction of fundamental frequencies under different failure modes. Eventually the fundamental frequency is gradually decreasing due to flexural cracks followed with the yielding of longitudinal reinforcement. Sherif et al[12] proposed the behavior of edge restrained concrete bridge deck slab reinforced with carbon FRP and glass FRP under concentrated loads, concluded that the proposed system showed better results using FRP reinforced bridge deck than normal RCC slab deck. Sanjeev et al[13] analyzed and discussed various nondestructive testing (NDT) methods in the last few decades and concluded that NDT gives efficient data results by revealing hidden defects and also to suggest repair or subsequent replacement of RCC structures.

2. EXPERIMENTAL INVESTIGATION

In this study a RCC deck slab is designed and casted to represent a RCC slab rural bridge. According to IRC: SP: 13:2004 in small bridges, the width should be sufficient to give a minimum clear carriageway of 4.25m for single lane bridges. According to IRC: SP: 20 small bridge on rural road could be generally taken as a bridge of total length between 6m and 30m. As per the economic point of view 6m can be adopted for such roads. Bridges of 6m length on rural roads are normally designed for single lane of IRC class A loading with impact. According to IRC: SP: 13:2004 M20 grade concrete for moderate condition of exposure and high strength deformed bars conformed to IS: 1786 are specified for RCC deck slabs.

2.1. Materials

The ordinary Portland cement of 53 grade having a specific gravity of 3.15 is used in this study. Natural aggregates are of two sized fractions, consisting of natural sand (0-2.36mm) and crushed coarse aggregates (4.75-12mm) (i.e. gravel). The reinforcement consists of 6 bars of 6mm diameter Fe415 grade with a spacing of 260mm c/c according to IRC 6:2014 along the longer direction and a spacing of 200mm c/calong the shorter direction. Table 1 and 2 gives the details of physical properties of aggregates and concrete mix proportion 1:2:4(as per IS 10962), respectively.

Table 1 Physical properties of the aggregate

Aggregate	Specific gravity	Water Absorption	Free Moisture
Sand	2.605	1.23%	Nil
Gravel	2.882	0.83%	Nil

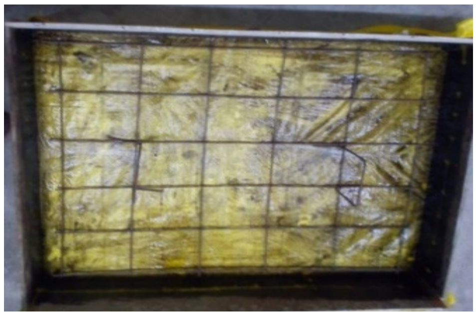
Table 2 Details of Mix proportion

Materials	Quantity
Cement	290 kg/m^3
Gravel	1363.25 kg/m^3
Sand	755.23 kg/m^3
Water	145 kg/m^3
w/c	0.5

2.2. Casting of Deck Slab

The prototype of a deck slab section dimensions are selected based on IRC codes. Dimension of prototype is 6m long x 4.25m wide x 0.435m thick. The test specimen is a ¼ scale model of the prototype. Figure 1 shows the reinforcement detailing and the casted deck slab of the scaled model of the bridge. Concrete strength is assumed to be the same in the prototype and model. For scaled model 5mm aggregates should be used. But as per IS 10962 minimum size of aggregates should be 12mm, therefore for the current study aggregates of size 5 to 12 mm is used in the model. The curing of the sample is done by using wet gunny bags for 28 days

(a)Formwork with reinforcement



(b) Casted Deck slab

Figure 1 Details of the deck slab

2.3. Test Setup and Procedure

Simply supported arrangement is made for RCC deck slab for experimentation. The instrumentation consists of automated impact hammer and accelerometer. The initial frequency of the slab bridge is obtained by the flowing procedure:The accelerometer is fixed on the slab at an appropriate position at the center of the slabto observe the vibration. The vibrations are measured in terms of frequency by hitting the slab using the impact hammer. Figure 2(a) shows the accelerometer sensor which is connected to a radio unit that sends a wireless signal to the controller connected to a computer as shown in Figure 2(b).

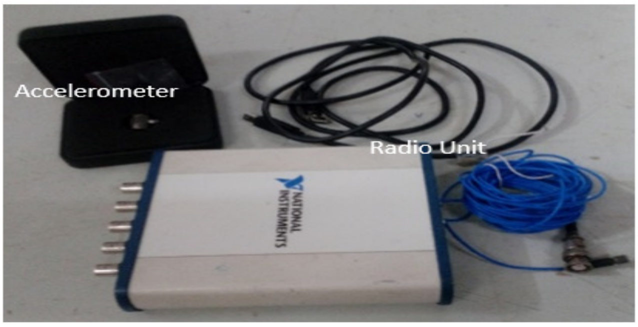


Figure 2 (a) Sensor Unit

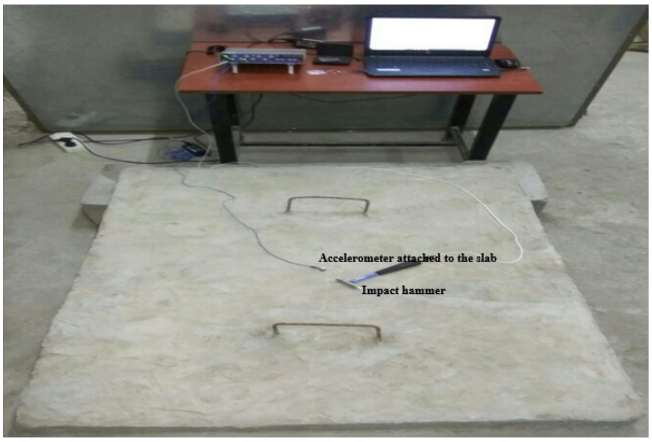


Figure 2 (b) Test Setup for Natural Frequency

The proposed damage detection method of RCC slab has been tested in a laboratory on loading frame (Figure 3). The deck slab is supported on four steel channel sections spaced at 1000mm c/c and are subjected to a monotonic single concentrated load over a contact area of 400 x 250 mm to simulate the footprint of the vehicle wheel load (57 kN class A) acting on the centre of the slab.

Figure 3 Tested RCC slab

Table 3 gives the details of the loading and damage observed on the slab during the various loading stages. The slab is loaded at the center by 3 steps of loadings as listed in the below table that progressively damaged the slab. Loading steps are based on design wheel load, wheel load with impact and till the crack appears on slab. It is unloaded after each load step. It is equipped with one accelerometer near the loading area and the vibration

displacements were measured by LVDT connected exactly under the load which sends the deflection records to the controller connected to a computer.

Table 3 Load steps

Load Step	Applied load(kN)	Description
0	0	No damage
1	15.8	No damage
2	24.2	First Crack
3	24	After Crack

3. ANALYTICAL INVESTIGATION

3.1. RCC Deck Slab Modeling

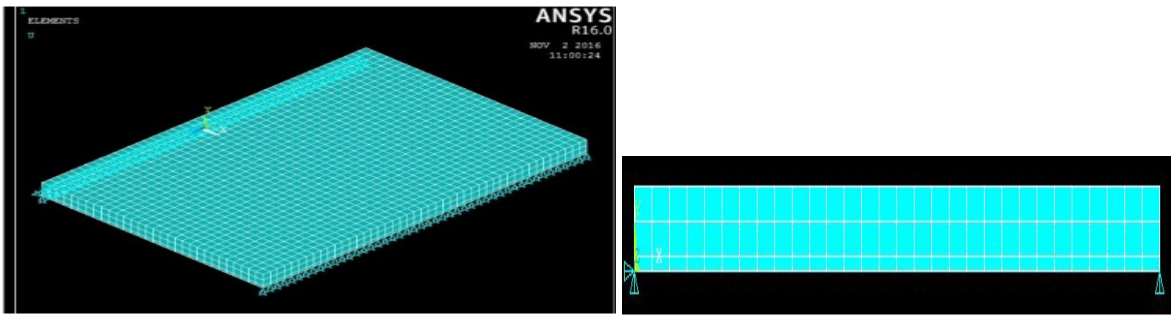
The finite element modeling and analysis of the RCC slab is carried out in ANSYS 16. The slab with the same specification as used in experiment is modeled as follows: block volume using SOLID65 element for concrete and LINK180 for steel reinforcement. Table 4 and 5 gives the details of linear elastic properties of concrete, steel and nonlinear properties of concrete, respectively.Figure 4 shows the Finite Element model (FEM), support conditions and reinforcement detailing of RCC slab. The load is applied to the bridge model as in the case of experimentation.

Table 4 Linear properties of concrete and steel

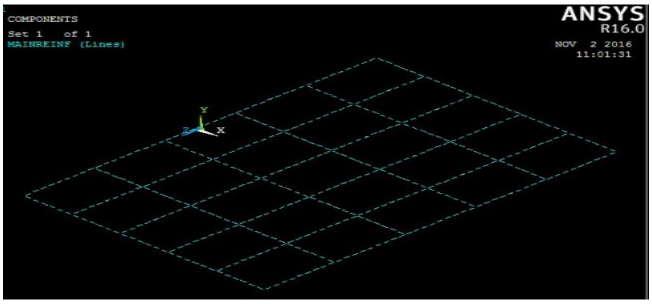
Material	Young's Modulus (N/mm^2)	Poisson ratio
Concrete	22360.68	0.2
Steel	200000	0.3

Table 5 Nonlinear properties of concrete

Shear transfer open crack	1
Shear transfer close crack	1
Uni-axial cracking stress N/mm^2	2
Uni-axial crushing stress N/mm^2	20



(a) Element modal (b) Support condition



(c)Reinforcement detailing

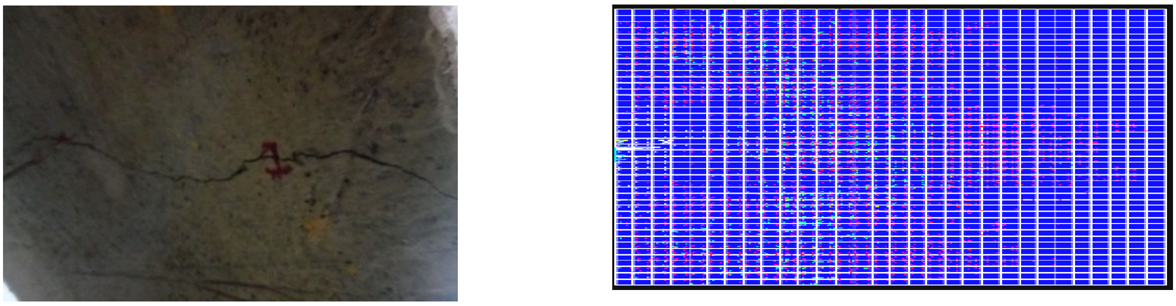
Figure 4 Finite Element Modeling of RCC slab

4. RESULTS AND DISCUSSION

The natural frequency and deflection of experimental and analytical methods are compared by using FFT and ANSYS, comparative results are tabulated in Table 6. After creating the model in ANSYS R16.0, the first modal frequency in modal analysis is found to be 96.75Hz and as per experimental it is 100Hz.The experimental and analytical results found to be close and thisvariation may be due to the isotropic considerations in the ANSYS and variability and deviation in elastic properties in the real structure. The design service load of the deck slab for scale model is 15.8 kNwhich is the maximum wheel loadthat includes live load factor of the design truck (class A vehicle).The design load with impact factor of 1.5 for the scale model is 24.2 kN. Table 6 gives the summarized results of experimental and analytical investigation, respectively. The first crack formation in experiment and analysis is shown in Figure 5.

Table 6 Summary of results

S.No	Load (kN)	Frequency (Hz)		Deflection (mm)	
		Experimental	ANSYS	Experimental	ANSYS
1	0	100	96.75	0	0
2	15.8	90.5	88.13	0.8	0.678
3	24.2	81.6	79.235	1.6	1.4113
4	24 (after crack)	80.28		5.2	

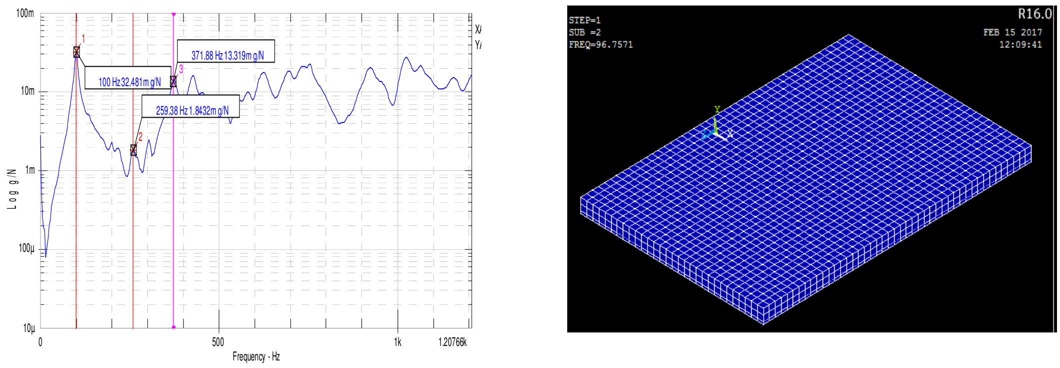


(a) Experimental (b) ANSYS

Figure 5 First crack formation

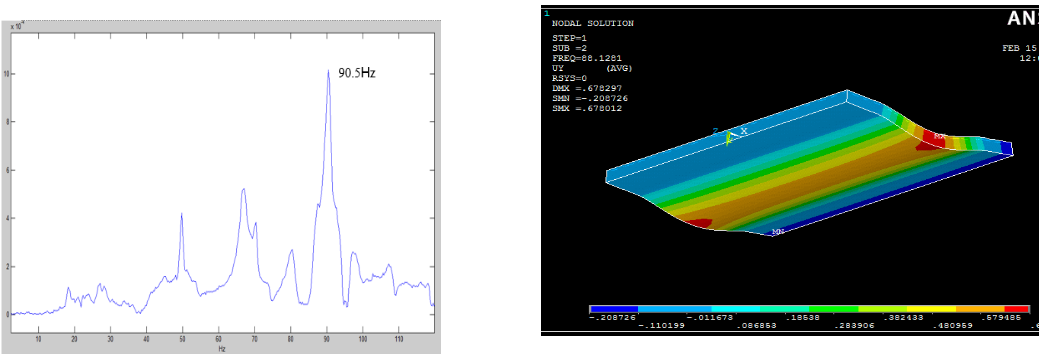
The vibration is measured in terms of voltage using accelerometer. This voltage signal is converted as a frequency signal by using FFT (Fast Fourier transform) in MATLAB. Figure 6 (a) and (b) shows the natural frequency of the deck slab. The frequency response of the deck

slab at design load i.e. 15.8 kN is given in Figure 7(a&b).For this loading the bridge deck is currently in good condition, so no damages are detected. Figure 8 (a&b) shows the frequency of the deck slab at 24.2 kN. For this load the first crack of 0.3mm wide appeared exactly in the center of slab is detected and oriented in the longitudinal direction parallel to the support conditions. The frequency response of the RCC slab from experiment after first crack is shown in Figure 9. The crack in the slab reduced the stiffness of the slab and this in turn affects the frequency of the slab. The frequency of the bridge after crack is decreased about 20% of its fundamental frequency.



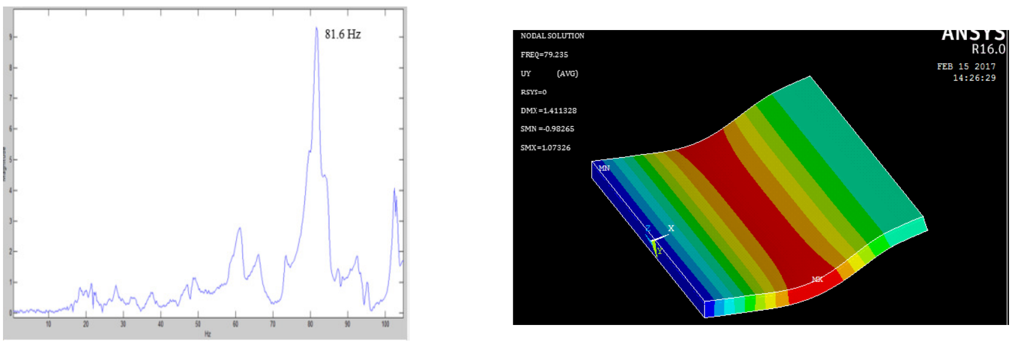
(a) Experiment (b) Analysis

Figure 6 Natural frequency of RCC deck slab



(a) Experiment (b) Analysis

Figure 7 Frequency of RCC deck slab for design wheel load



(a) Experiment (b) Analysis

Figure 8 Frequency of RCC deck slab for design wheel load with impact

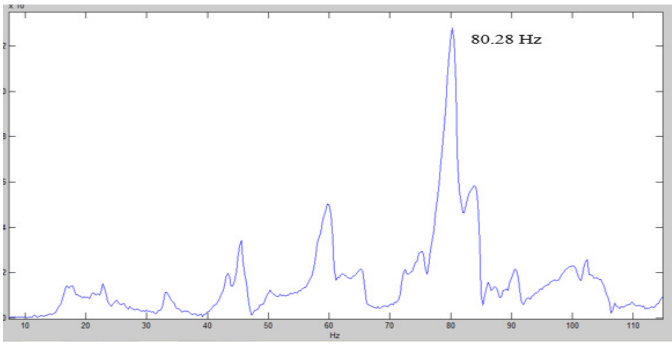


Figure 9 Frequency response after crack from experiment

The load versus deflection behavior of RCC deck slab for the design wheel load and design wheel load with impact is shown in Figures 10and 11, respectively. Gradual loading increment caused relatively small or permanent deformation. The crack width is significantly increased from 0.3mm at wheel load with impact and to 0.90 mmafter cracking. This behavior indicates that there is a considerable loss in the stiffness. Initial stiffens for the design load is 19.75 kN/mm and for impact load is 15.125 kN/mm.So with the increasing of crack width after the impact design load the stiffness of slab is decreased around 23 %. This causes a decreasing the frequency and it indicates that the failure of concrete can be detected from there duction of frequency. Figure 12 shows nonlinear behavior for reduced force and more deflection of 5.2mm after the first crack.

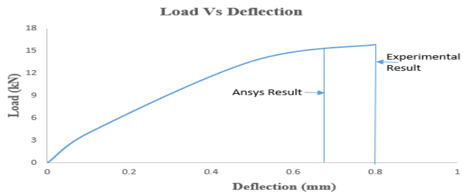


Figure 10 Load versus Deflection for design load

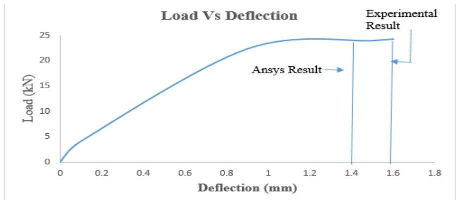


Figure 11 Load versus Deflection for design load with impact load

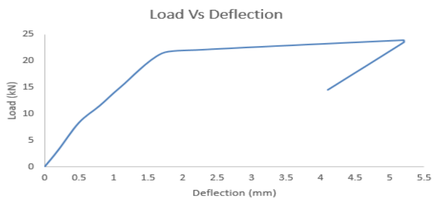


Figure 12 Load versus Deflection after crack

5. CONCLUSION

The condition monitoring of RCC deck slab bridge model is studied by conducting experimental and analytical investigation. The frequency, deflection and width of cracks are used as parameters to study the health condition of the bridge. The damage detection is successful in identifying the reduction in frequency on the RCC slab deck.The reduction in

stiffness after appearance of the first crack is 23 %. The frequency is significantly decreased from 100 Hz to 80.28Hzdue to flexural cracks that occurred in concrete. The experimental and analytical results are nearly equal and the crack pattern and frequency reduction are adequately simulated using ANSYS. This kind of validation would be very useful to the researchers to reduce the number of experiments for complicated structures.

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